Diffuse Heating of Volcanoes Prior to Eruption

2014 Ontake phreatic eruption
>60 fatalities

[credit: BBC news]

2019 AGU FALL MEETING
10 December 2019

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Paul Lundgren

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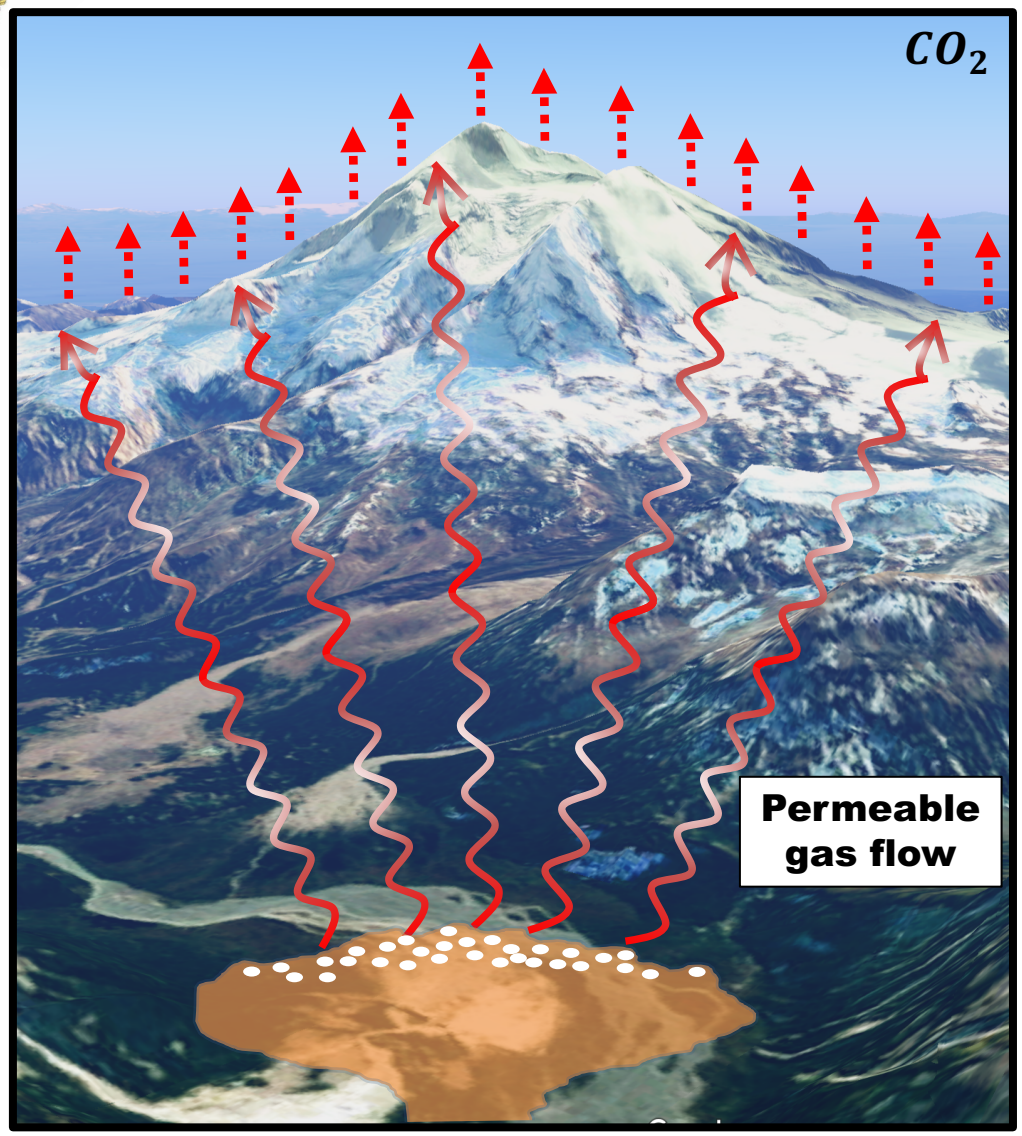
HYPOTHESIS: Diffuse outgassing warms volcanic edifices



[credit: Google Earth, NASA]

- **Degassing magma reservoir**
  [e.g., Girona et al., 2014; Stix and de Moor, 2018]
- **Diffuse outgassing**
  [e.g., Chiodini et al., 1998; Hernández et al., 2001; Schwandner et al., 2004]
- **CO_2 (and other gases) transport heat towards the surface**
  [e.g., Melián et al., 2010; Chiodini et al., 2014; Epiard et al., 2017;]

  What happens with that heat?
- **Difficult from the ground …**

⇩

… from space?

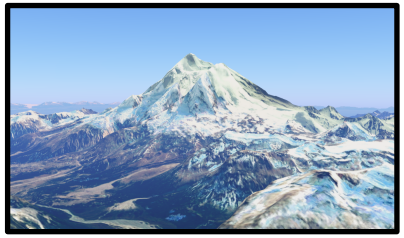
RESEARCH QUESTIONS

1. Do thermal emissions vary significantly before eruptions?

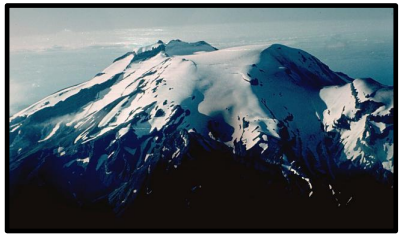
2. How are these thermal emissions related to subsurface pressure and deformation?

Method
Results
Discussion

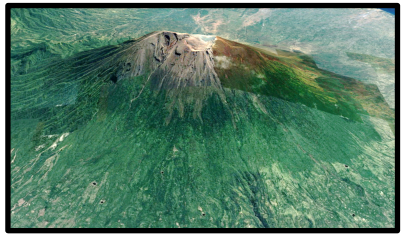
Redoubt
(USA) / 2009



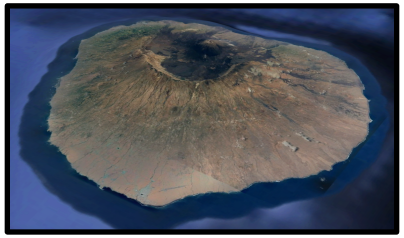
Calbuco
(Chile) / 2015



Agung
(Indonesia) / 2015



Pico do Fogo
(Cape Verde) / 2014

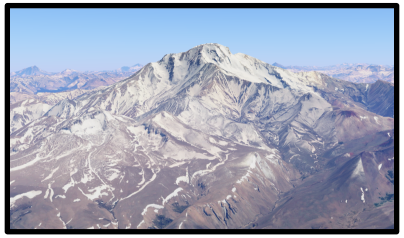


El Hierro
(Spain) / 2011

Ontake
(Japan) / 2007, 2014

Ruapehu (New Zealand)
2006, 2007

Domuyo (Argentina)
2003, 2007, 2012



RESEARCH QUESTIONS

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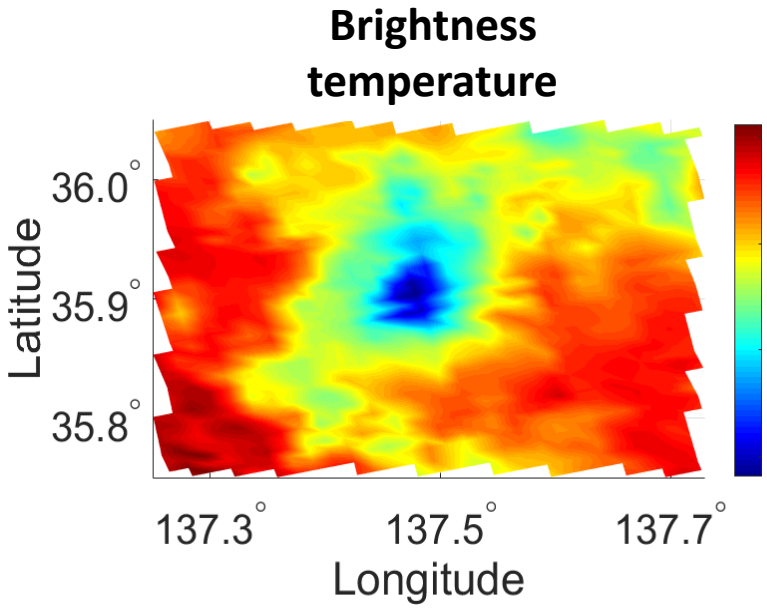
1 **Radiance data (Level 1B MODIS Terra/Aqua; band 31: 10.780-11.280 µm; 1x1 km)**

16.5 years of data
~ 3 – 8 scenes per day
> 159,000 scenes
> 25 TB

2 **Calculation of the median anomaly $\overline{\delta T}$ (°C)**



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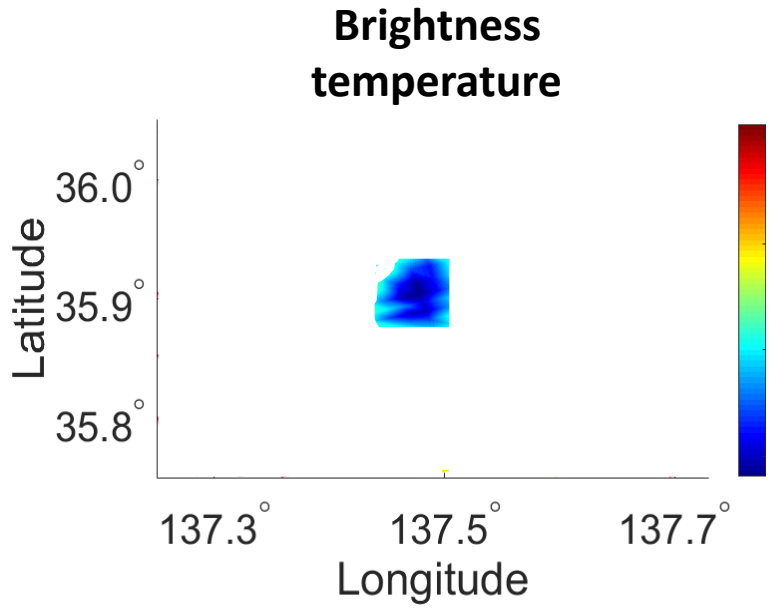

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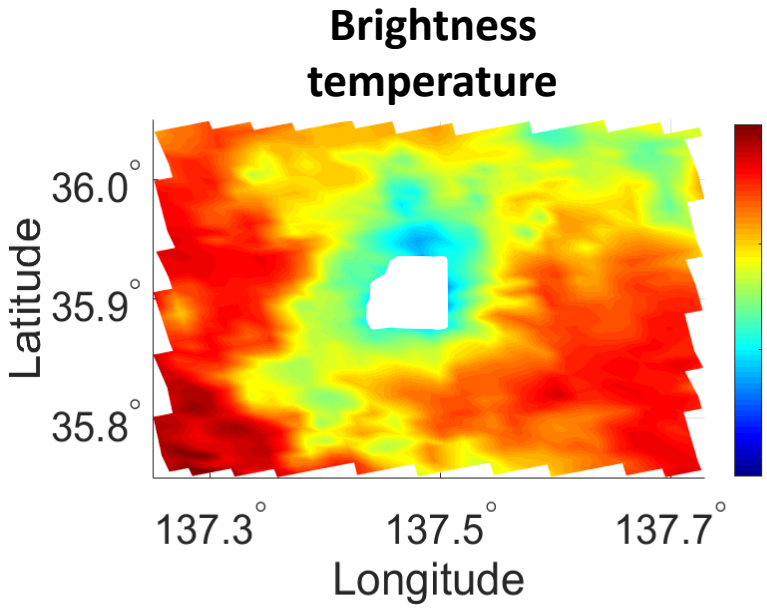

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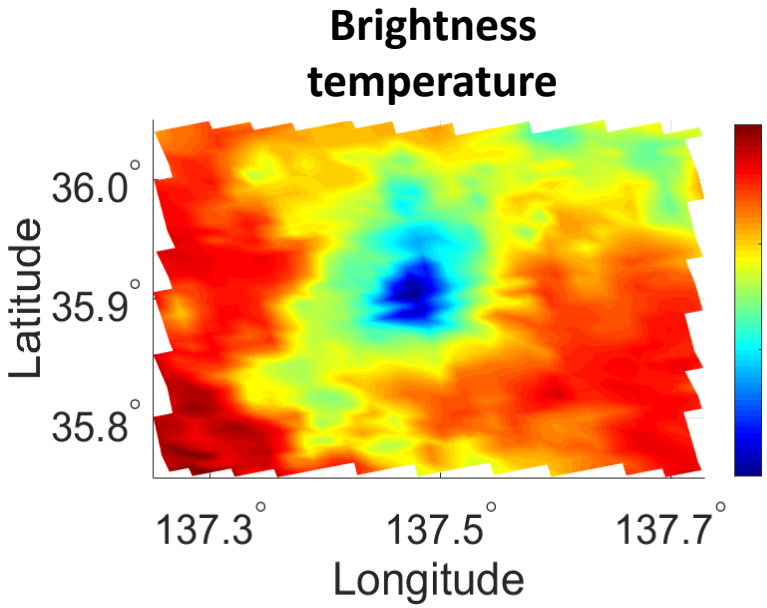
Enhanced iterative filtering technique
Long-term variations (~ years)



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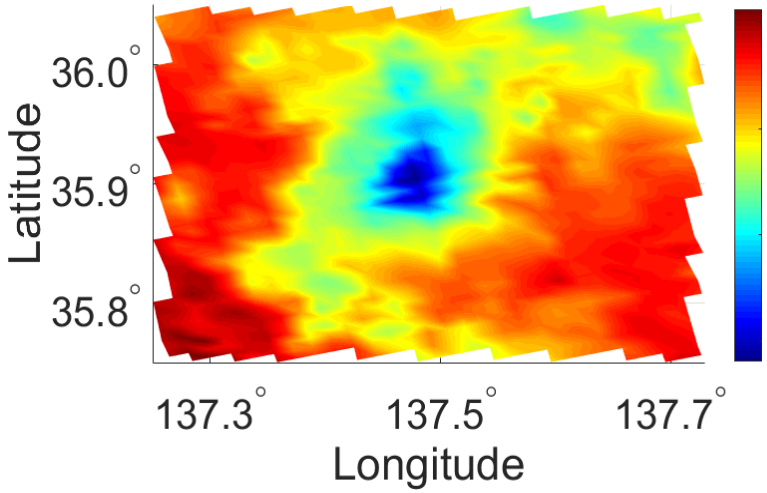
Brightness temperature



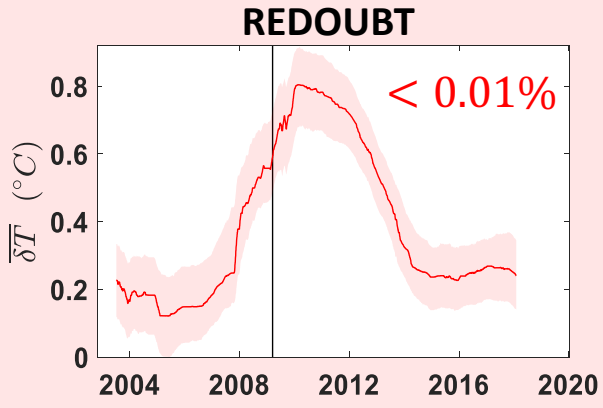
2. **Calculation of the median anomaly $\overline{\delta T}$ (°C)**

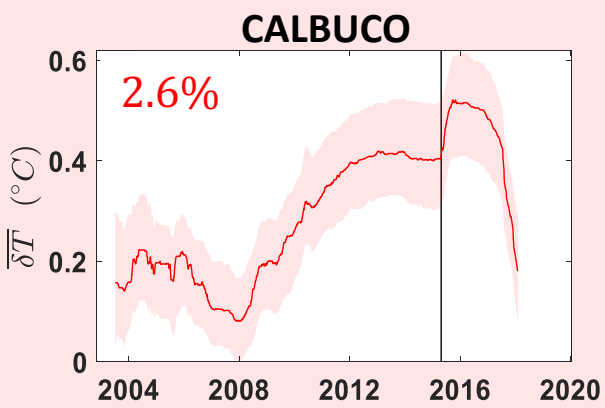
Enhanced iterative filtering technique
Long-term variations (~ years)

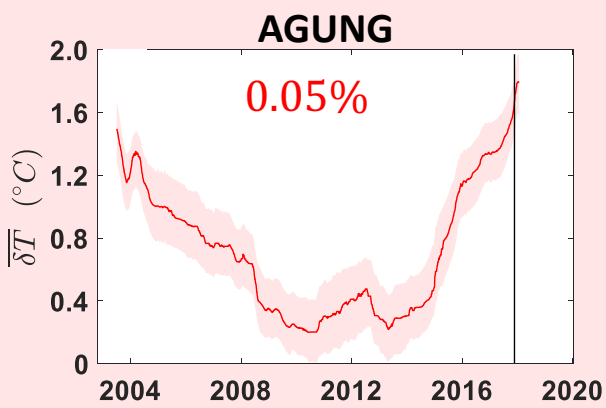
3. **Statistical tests**

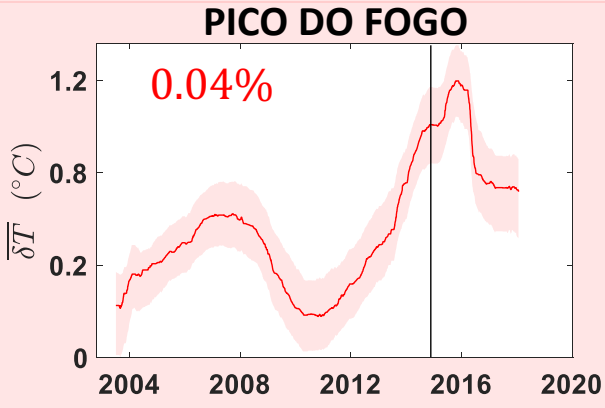
Bootstrapping + Monte Carlo to calculate uncertainty of $\overline{\delta T}$

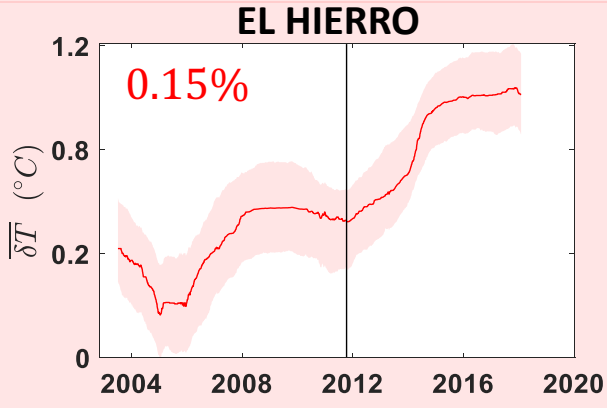
Monte Carlo to calculate the probability of obtaining the maximum amplitude of $\overline{\delta T}$ by chance

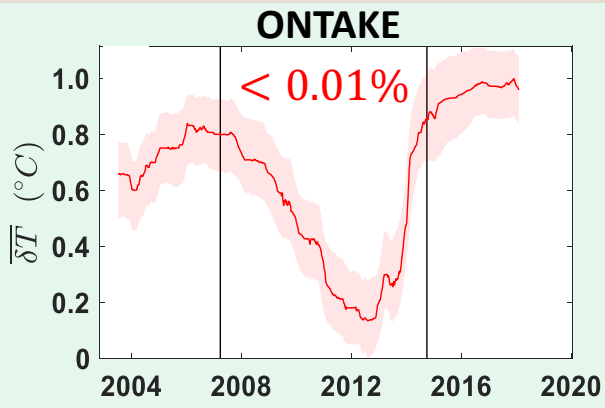


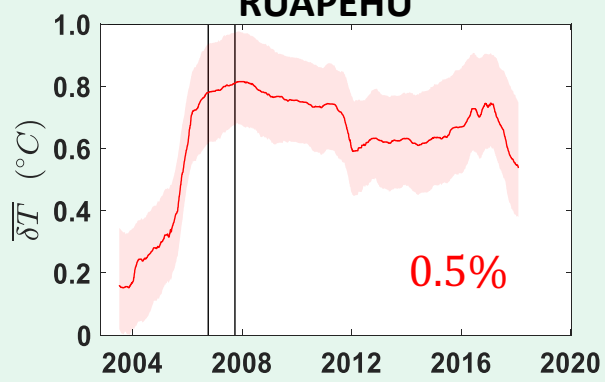


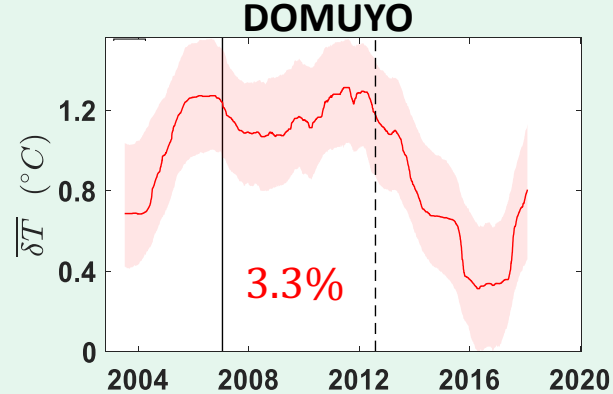








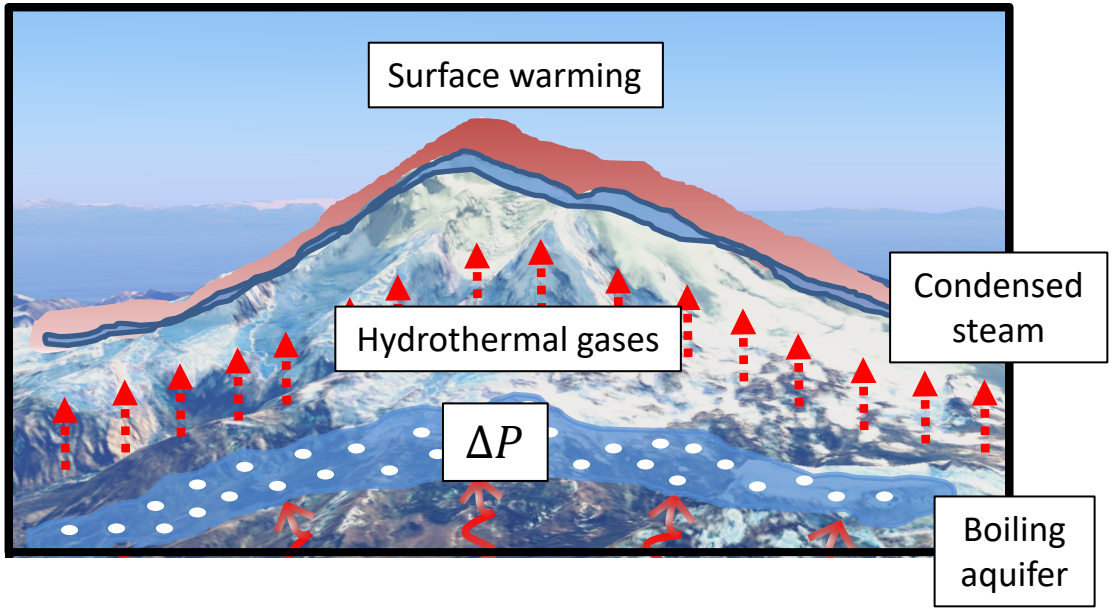




Take-home message:

Volcanoes get hot for years prior to eruption

[Girona et al., *In review*]

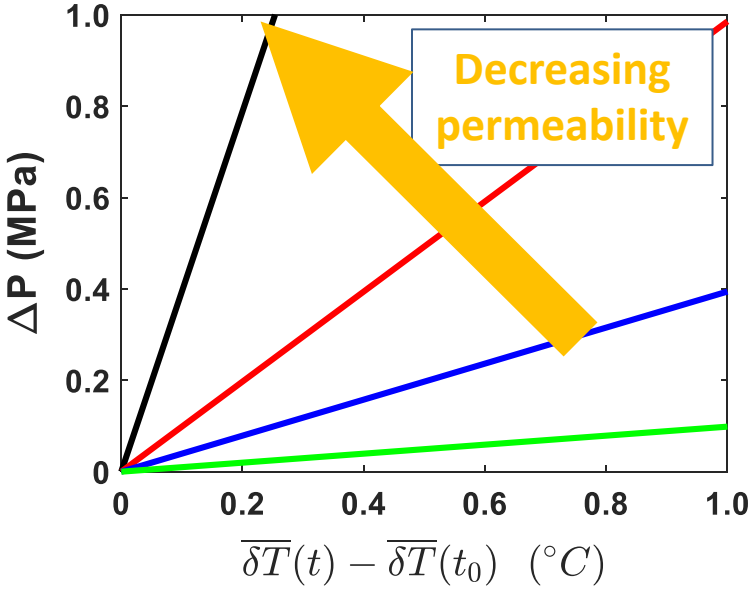


- **Surface warming reflects the pressure conditions of hydrothermal systems**
- **Consistent with geochemistry in fumarolic fields**
  [e.g., Cioni et al., 1994; Chiodini et al., 2001]

- **Momentum, energy, and mass conservation**
- **Steady-state**
  Surface warming observed → critical ΔP

$$\Delta P = \frac{2\mu R\left(T_{aq}+T_c\right)\sigma\varepsilon T^3}{\rho_c g\kappa M\chi L_{ev}}\left[\overline{\delta T}(t)-\overline{\delta T}(t_0)\right]$$

Overpressure **Surface warming**



RESEARCH QUESTIONS

1 Do thermal emissions vary significantly before eruptions?

- **R1**:

YES. The thermal emissions of the volcanic flanks increased prior to the most recent eruptions of the target volcanoes.

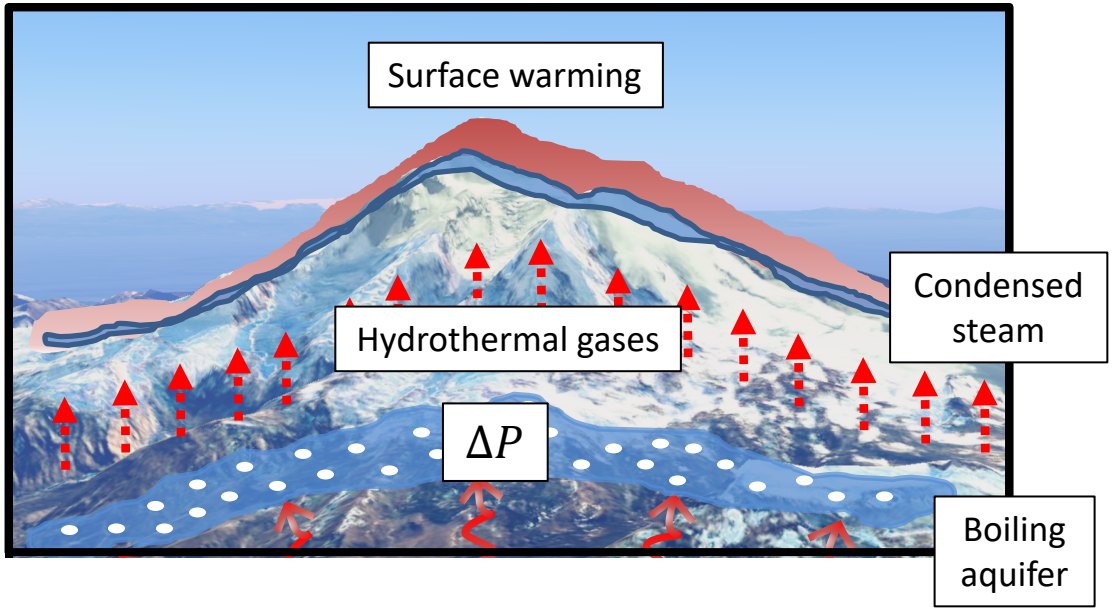
First time that long-term diffuse thermal unrest is detected.

2 How are these thermal emissions related to subsurface pressure?

- **R2**:

They reflect the pressure conditions of hydrothermal systems.

Through the condensation of hydrothermal H_2O below the surface.



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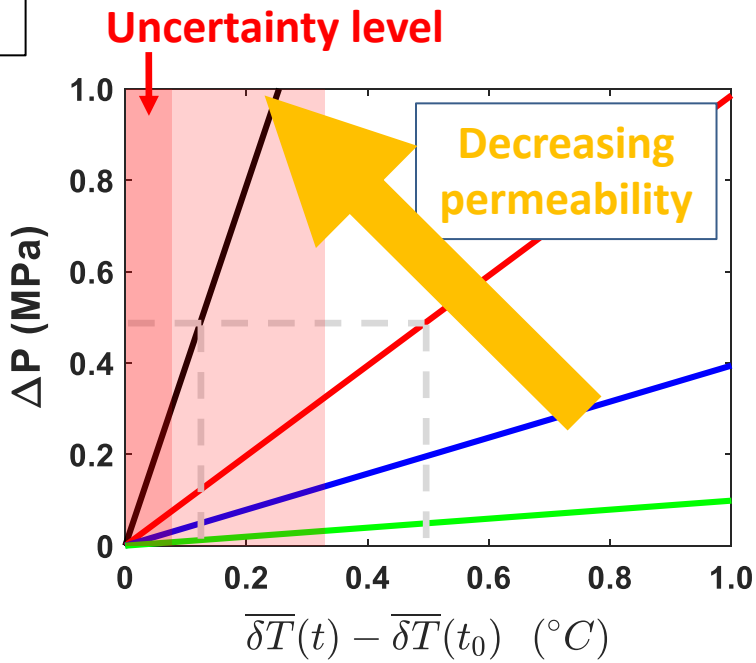
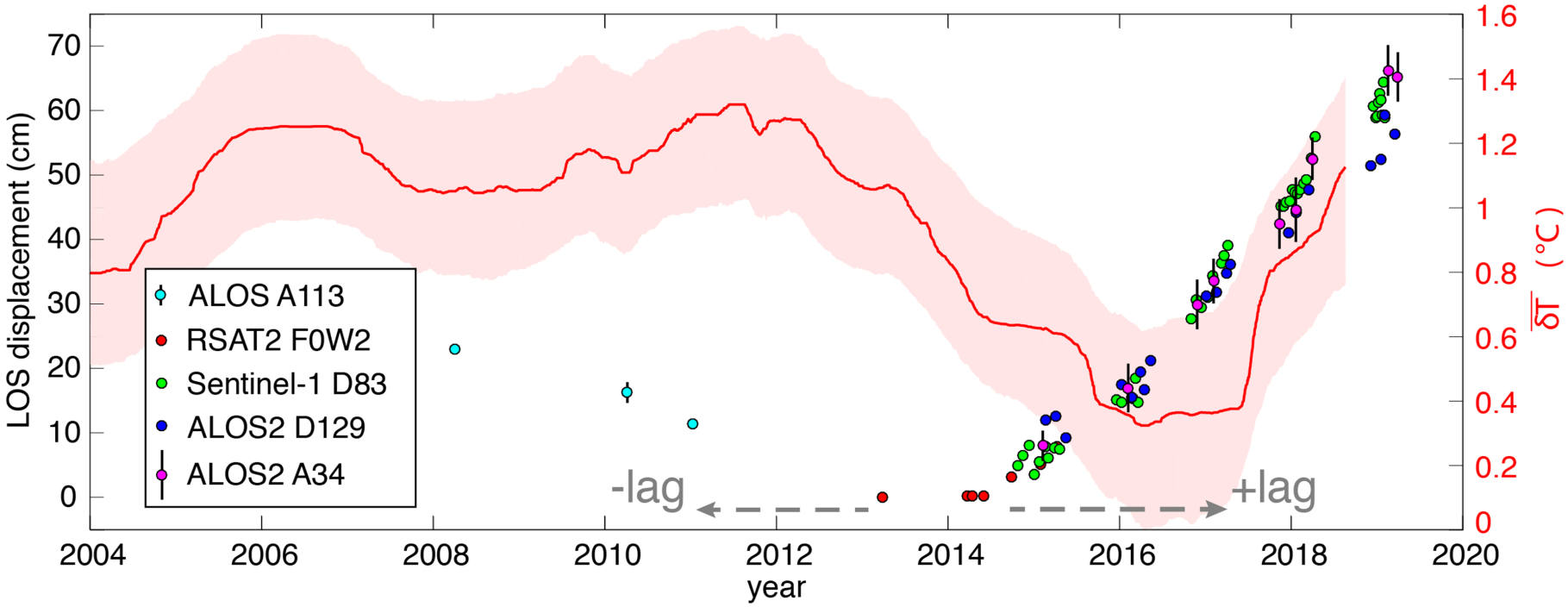
Overpressure — **Surface warming**

Decrease the uncertainty of surface warming detections…
…improving algorithms and infrared imaging capabilities



WHAT'S NEXT?

- **To combine with other observables.**



WHAT'S NEXT?

- To combine with other observables.
- To identify the active thermal areas.
- To decrease the uncertainty.
- To extend this study to more and other type of volcanoes.
- To explore the response of hydrothermal systems to earthquakes.
- Extraterrestrial thermal processes.
- Multi-scale approach: To combine HIGH SPATIAL RESOLUTION with HIGH TEMPORAL RESOLUTION.

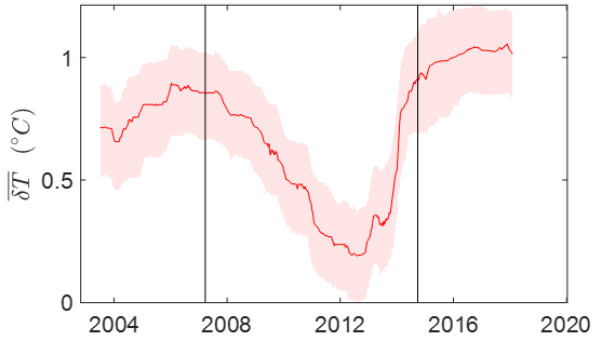
2 Heat balance analysis: $\Delta\Phi_d(t;t_0) \approx 4\sigma\varepsilon T^3\left[\overline{\delta T}(t) - \overline{\delta T}(t_0)\right]$

VOLCANO	YEAR OF ERUPTION	$\Delta\Phi_d(t;t_{min})$ (W/m^2)	
Redoubt	2009	$\mathbf{1.89}$ $(1.07-2.71)$	magma-driven
Calbuco	2015	$\mathbf{1.50}$ $(0.81-2.19)$	
Ontake	2007	$\mathbf{2.9}$ $(1.8-4.0)$	gas-driven
	2014	$\mathbf{3.2}$ $(1.9-4.5)$	
Ruapehu	2006-2007	$\mathbf{2.9}$ $(1.7-4.1)$	
Domuyo	2007	$\mathbf{4.1}$ $(1.7-6.5)$	
	2012	$\mathbf{3.8}$ $(1.4-6.2)$	

Heat flow varies more in volcanoes with gas-driven eruptions than in volcanoes with magma-driven eruptions!

3 **No direct link between SURFACE WARMING and SURFACE DEFORMATION**

ONTAKE



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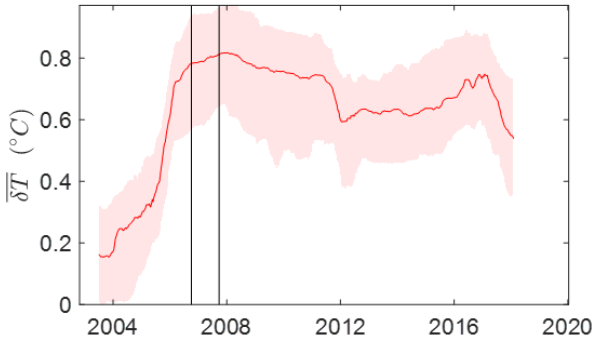
RUAPEHU



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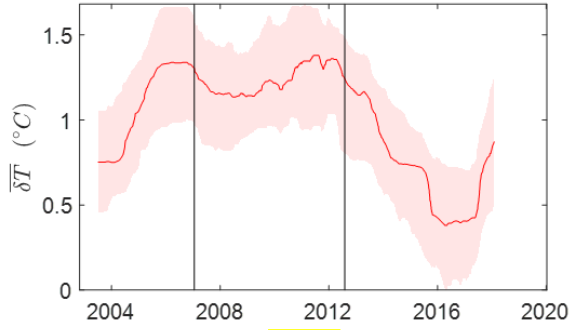
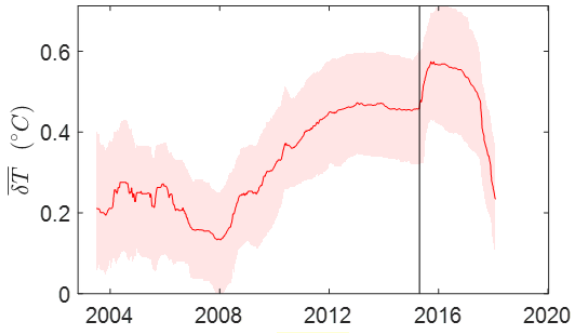
DOMUYO



3.3%

CALBUCO



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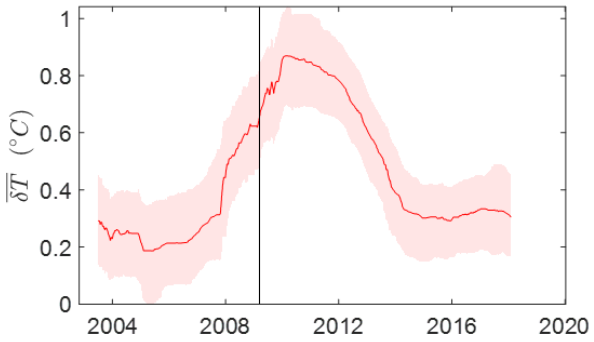
REDOUBT



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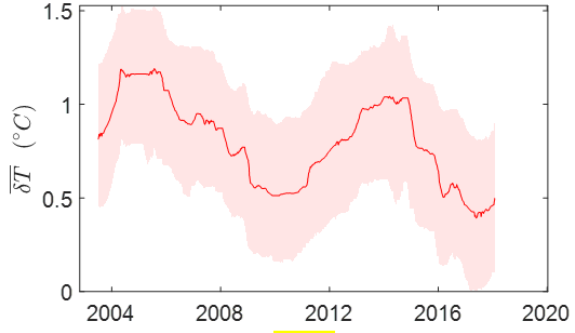
BLANCA PEAK



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Results
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Magmatic eruptions

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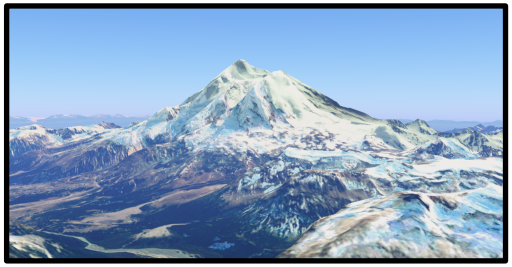

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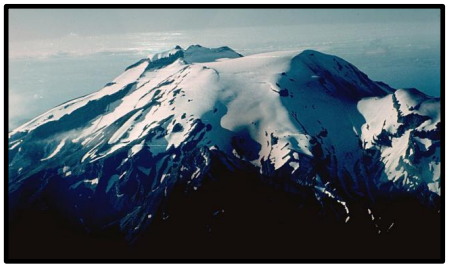
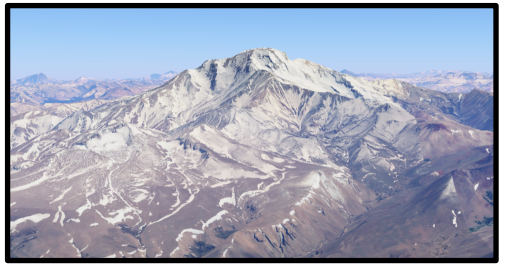


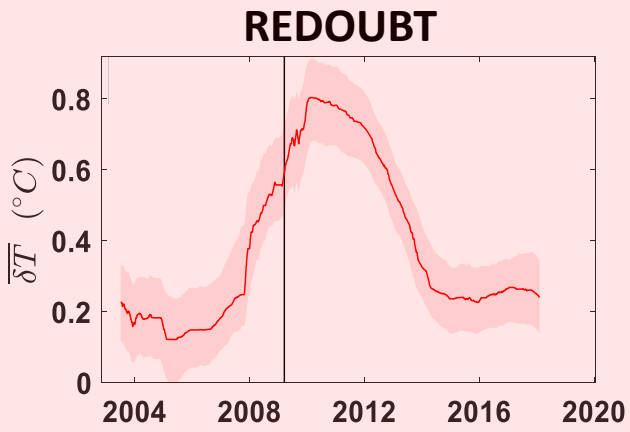
Gas explosions

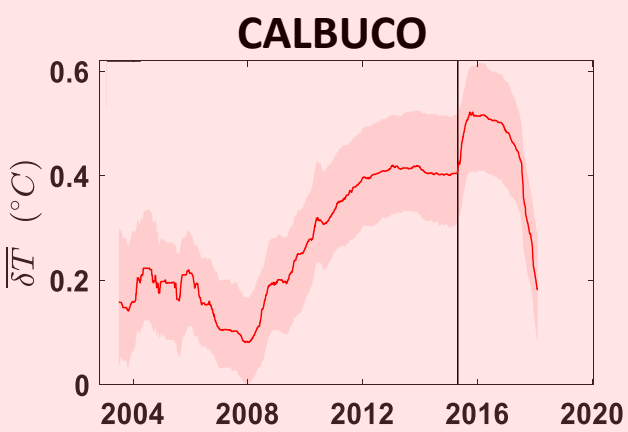
Ontake (Japan)
2007, 2014

Ruapehu (New Zealand)
2006, 2007

Domuyo (Argentina)
2003, 2007, 2012





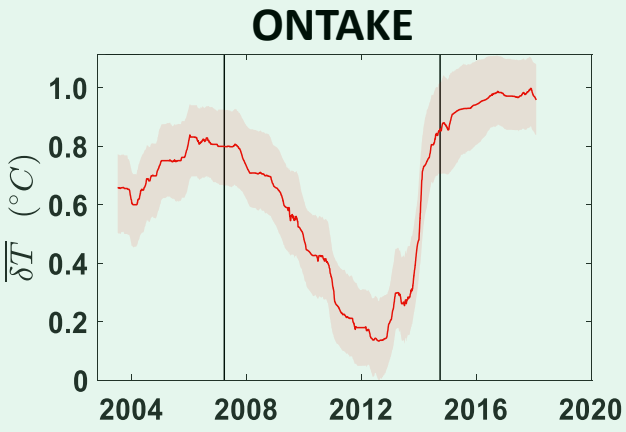


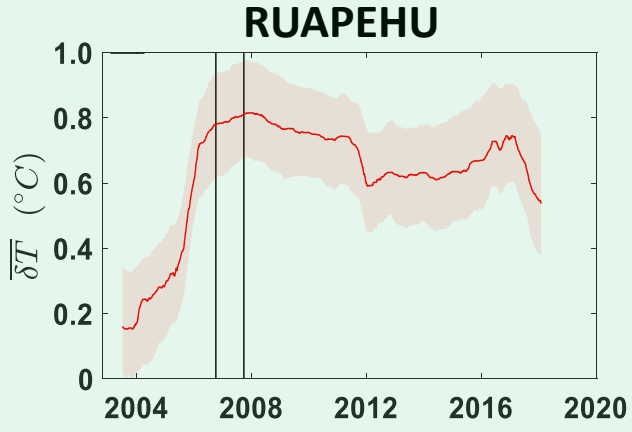
Probability of obtaining the observed amplitudes by chance:

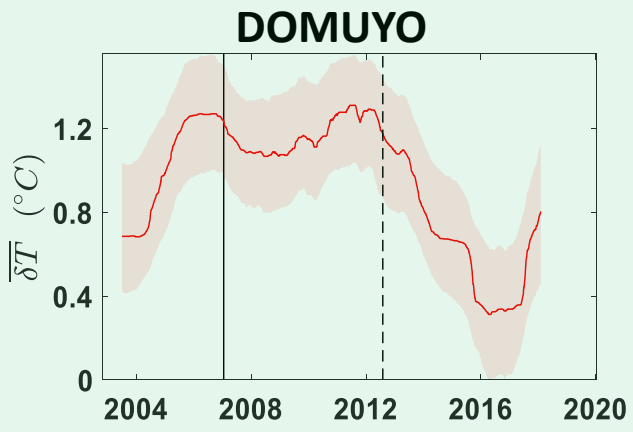
← **Magmatic eruptions**

Gas explosions

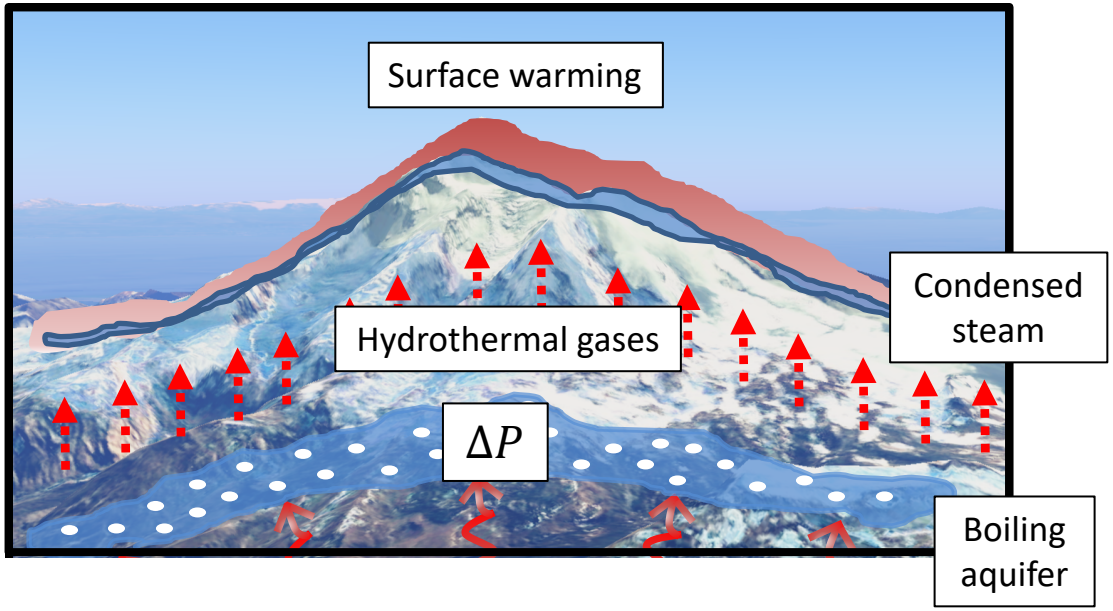
↓







Do you remember the title? → **Volcanoes get hot for years prior to eruption**



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Overpressure **Surface warming**

Surface warming observed → critical ΔP

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